

THE APPLICATION OF UNMANNED ROTARY-WING AIRCRAFT IN
TACTICAL LOGISTICS IN SUPPORT OF JOINT OPERATIONS

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General Studies

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ABSTRACT

THE APPLICATION OF UNMANNED ROTARY-WING AIRCRAFT IN TACTICAL LOGISTICS IN SUPPORT OF JOINT OPERATIONS, by MAJ Luke T. Chivers, 69 pages

This thesis is a thorough examination and evaluation of unmanned rotary-winged aircraft performance and capabilities during tactical logistics missions, in permissive and non-permissive environments. It analyzes the Department of the Army's interests in the development and integration of rotary-wing unmanned aircraft to execute tactical logistics in support of joint operations. The thesis' research methodology examines unmanned rotary-wing aircraft to 11 different criteria and determines whether its capabilities are more effective than manned rotary-wing aircraft currently in the United States Army. Of the 11 criteria, this study determines that the three most important evaluation criteria when comparing manned and unmanned rotary-wing aircraft are the system that performs consistently in severely degraded visibility, relatively autonomously, and with little maintenance costs. These three criteria best describe the advantages and disadvantages of both systems in relation to tactical resupply missions throughout the joint operating environment. The results of this comparison is a system capable of decreasing risk to flight crews, providing supplies to ground forces in critical situations, and saving taxpayer money. Based on this comparison, the United States Army can determine that rotary-wing unmanned aircraft support the ground force commander's mission to execute tactical logistics missions in the joint environment.

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ACRONYMS

DARPA	Defense Advanced Research Projects Agency
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities
GPS	Global Position System
IIMC	Inadvertent Instrument Meteorological Conditions
ISR	Intelligence, Surveillance, and Reconnaissance
NVGs	Night Vision Goggles
UCAR	Unmanned Combat Armed Rotorcraft
U.S.	United States

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CHAPTER 1

INTRODUCTION

Overview

Unmanned systems are ideal for missions considered to be dull, dirty, or dangerous.¹

— General Dynamics, *Future Modular Force Resupply Mission for Unmanned Aircraft Systems (UAS)*

Joint Publication 3-52 defines an unmanned aircraft as “an aircraft or a balloon that does not carry a human operator and is capable of flight under remote control or autonomous programming.”² Additionally, Joint Publication 3-52 further defines an unmanned aircraft system as “that system whose components include the necessary equipment, network, and personnel to control an unmanned aircraft.”³ Over the last 12 years, fixed-wing unmanned aircraft have played a significant role in the Global War on Terror. In established war zones like Iraq and Afghanistan, fixed-wing unmanned aircraft precision strikes have been a common occurrence, their destructive effects often recorded in detail by global media and news organizations. In undeclared war zones like Yemen and Pakistan, military forces have conducted precision unmanned aircraft strikes intended to diminish or eliminate terrorist safe havens. Fixed-wing unmanned aircraft have even been utilized in conflicts other than the Global War on Terror, such as helping North

¹General Dynamics. *Future Modular Force Resupply Mission for Unmanned Aircraft Systems (UAS)* (Fairfax, VA: General Dynamics, 2010), 11.

²Chairman of the Joint Chiefs of Staff, Joint Publication (JP) 3-52, *Joint Airspace Control* (Washington, DC: Government Printing Office, May 2010), GL-13.

³*Ibid.*

Atlantic Treaty Organization (NATO) forces liberate Libya. As these examples illustrate, the popularity of unmanned aircraft in all services of the United States military has risen over the last several years.⁴ Many manned aircraft platforms are beginning to see their roles and missions diminish, only to be replaced by the capabilities of an unmanned aircraft. Furthermore, the successes achieved by the U.S. military in precision strikes by fixed-wing unmanned aircraft have sparked innovation in the development of other types of unmanned aircraft for other operational roles. One mission set the military should explore further is rotary-wing unmanned aircraft and its performance in a tactical logistics role. For example, The U.S. Navy and Marine Corps have utilized rotary-wing unmanned aircraft for several years. Additionally, U.S. allies like the United Kingdom are asking for the American industrial base to develop and support their need for rotary-wing unmanned aircraft.⁵

Despite the increasing uses of rotary-wing unmanned aircraft, the Department of the Army has yet to capitalize on their benefits to the extent the U.S. Navy and U.S. Marine Corps. Likewise, the U.S. Army is not likely to pursue new technology in the unmanned rotary-wing aircraft arena in the near future. Due to their lack of new technology, the U.S. Army may fall behind its sister services counterparts in unmanned rotary-wing development, especially in its support of tactical logistics. The tactical logistics mission is a critical operation rotary-wing unmanned aircraft can greatly impact.

⁴Dan Parsons, "Worldwide, Drones Are In High Demand," *National Defense*, May 2013, <http://www.nationaldefensemagazine.org/archive/2013/May/Pages/Worldwide,DronesAreinHighDemand.aspx> (accessed September 30, 2013).

⁵Development, Concepts and Doctrine Centre, Joint Doctrine Note (JDN) 2/11, *The UK Approach to Unmanned Aircraft Systems* (Shrivenham, UK: United Kingdom Ministry of Defence, March 2011), 7-1.

For example, the ability to rapidly deploy, haul cargo both internally and externally with precision, and fly in adverse meteorological conditions can provide the U.S. Army, especially its ground forces, a much needed combat multiplier on the battlefield.

Purpose of Study

The purpose of this thesis is to research cargo rotary-wing unmanned aircraft, compare them to 11 evaluation criteria, and determine if the U.S. Army could more effectively exploit the capabilities of these aircraft in support of tactical logistics. This thesis will examine the need and feasibility of cargo rotary-wing unmanned aircraft to support tactical logistics, as well as the potential changes in tactics, techniques, and procedures that could result. To frame the analysis, this thesis considered the 11 criteria used in a 2010 General Dynamics study addressing the engineering and development of cargo-unmanned rotary-wing aircraft.⁶ These 11 criteria are: day and night operating capability, all-weather capability, ability to land in a confined area, speed of delivery, low maintenance needs, mission endurance, ability to carry a wounded individual, load capacity greater than 2,000 pounds, low noise signature, mission range, and autonomy. This thesis will narrow the 11 criteria and focus only on those criteria that enable the U.S. Army to limit exposure of pilots and troops to the enemy, conduct operations in adverse meteorological conditions, and lastly, save time and money from reduced maintenance costs.

This is a qualitative research study, and comparison is limited to existing cargo rotary-wing manned and unmanned aircraft programs resident within the Department of

⁶General Dynamics, *Future Modular Force Resupply Mission for Unmanned Aircraft Systems (UAS)*, 60.

Defense, programs utilized by allied militaries, and technology currently under development in the civilian sector. Finally, this research will explore potential organizational changes and tactics, techniques, and procedures introduced as a result of fielding unmanned rotary-wing aircraft to current Army organizational structures.

Primary Research Question

Should the Department of the Army develop and integrate rotary-wing, unmanned aircraft to support tactical logistic missions in support of joint operations?

Secondary Research Questions

What can an unmanned rotary-wing aircraft provide to tactical logistic missions that a manned helicopter cannot?

What advantages do unmanned rotary-wing aircraft provide to tactical logistics mission that manned helicopters do not?

Why has the U.S. Army not researched, developed, and utilized cargo rotary-wing unmanned aircraft capabilities, similar to the U.S. Navy and Marine Corps?

What potential organizational restructuring within the Department of the Army is necessary to field cargo rotary-wing unmanned aircraft?

What potential tactical, technical, and procedural changes would the Department of the Army have to implement to properly utilize cargo rotary-wing unmanned aircraft?

Assumptions

Loading and unloading a cargo rotary-wing aircraft is a simple task military service members can perform with little training; for the purposes of this study, these tasks should be considered similar for either manned or unmanned aircraft. The rigging of

external sling loads to rotary-wing aircraft is a specialized task performed by specialized personnel; for the purposes of this study, this is a similar process for both manned and unmanned rotary-wing aircraft. Lastly, personal safety of untrained personnel operating around unfamiliar aircraft is a major consideration during internal and external load operations for both types of aircraft.

Definitions

The U.S. Army and Joint doctrine broadly define logistics to include supply, transportation distribution maintenance, field service, operational contracting, and general engineering.⁷ For the purpose of this study, the term logistics is defined as the transportation of all supply classes to tactical ground units. The modes of transportation may include internal and external loads or airdrops from a manned or unmanned rotary-winged aircraft.

Limitations

This study will focus primarily on the resupply and logistics at the tactical unit level. Specifically, it will address technical aspects of aircraft, as they relate to tactical and operational levels of warfare. This study will only compare one cargo-unmanned rotary-wing aircraft to multiple cargo and utility manned aircraft. This study is limited to unclassified sources and details on classified technological advances or tactical usages cannot be provided.

⁷Chairman of the Joint Chiefs of Staff, Joint Publication (JP) 4-0, *Joint Logistics* (Washington, DC: Government Printing Office, July 18, 2008), I-9.

Conclusions

The results of this study thesis will help inform the U.S. Army regarding augmenting manned rotary-wing aircraft with unmanned rotary-wing aircraft to support small tactical logistics missions at critical points on the battlefield. The U.S. Army should evaluate the cost of operating a small fleet of unmanned rotary-wing aircraft to determine if it fills a known capability gap in manned rotary-wing logistics missions. The suggested capability gap is the ability to resupply small ground forces in adverse weather and low illumination conditions, without risking crewmember lives. For this to be possible, the U.S. Army would have to trust immature autonomous technology to achieve the benefits of cheaper long-term aircraft maintenance. The cargo-unmanned rotary-wing aircraft not only is advantageous during high-risk manned rotary-wing aircraft missions, but also offers potential solutions to ground missions such as bypassing the roadside bomb threat encountered during ground logistic convoys. These missions will only be briefly discussed in this study. Furthermore, the recent success of unmanned rotary-wing aircraft in the U.S. Navy and Marine Corps, along with their extensive research on this subject, should facilitate a smoother Army transition.

This thesis will review literature related to unmanned rotary-wing aircraft and its potential effects on tactical logistics missions in support of joint operations.

CHAPTER 2

LITERATURE REVIEW

The purpose of this study is to qualitatively analyze rotary-wing unmanned aircraft resident in the Department of Defense, allied militaries, and civilian corporations. This analysis will determine if the Department of the Army can effectively employ and utilize rotary-wing unmanned aircraft to conduct tactical logistic missions to support joint operations. This chapter will review relevant civilian and military technical references; military doctrine and technology in the U.S. Marine Corps, Navy and Army; U.S. Government policy in the Defense Advanced Research Projects Agency (DARPA); emerging uses amongst coalition partners; and opposing arguments to the research, development, and experimentation of cargo unmanned rotary-wing aircraft in support of tactical logistics missions.

Technical References

Over the last decade, research on unmanned aircraft has focused on fixed-wing systems, due to their major role in the Global War on Terrorism, and there is little research on rotary-wing unmanned aircraft. However, in 2010, Reg Austin completed a comparative study of fixed and rotary-wing unmanned aircraft titled, *Unmanned Aircraft Systems: UAVS Design, Development, and Deployment*. Austin has been in academia since 1991 writing on the subject of unmanned aircraft. He has practiced as an aeronautical engineer since 1945 and served as Chief Project Engineer for Bristol Aeroplane Company, Westland Helicopters Company, and Auster Helicopter Limited.⁸

⁸Reg Austin, *Unmanned Aircraft Systems: UAVS Design, Development, and Deployment* (West Sussex, UK: A. John Wiley and Sons, 2010), Foreword.

Austin was also a consultant in North Atlantic Treaty Organization's Vertical Take Off and Landing unmanned aircraft group. His research was conducted in response to the mass production of fixed and rotary-wing unmanned aircraft over the last several years. In *Unmanned Aircraft Systems: UAVS Design, Development, and Deployment*, Austin describes in detail the flight characteristics of both rotary and fixed-wing systems.⁹ His analysis highlights the advantages and disadvantage of the two systems. For example, rotary-wing unmanned aircraft showed better resilience to strong wind gusts than fixed-wing unmanned aircraft. Austin notes many more technical, tactical, and operational differences between the two systems that are useful to this study. Similar to Austin's study, this thesis will focus on the technical and tactical impacts rotary-wing unmanned aircraft have on tactical logistics and resupply missions.

This literature review shows that prior to 2004 rotary-wing unmanned aircraft technology was not a significant U.S. military interest. Austin's study is one of the few detailed publications of multiple types of unmanned aircraft including rotary-wing. His discussion of rotary-wing aerodynamics, engines, and acoustics, as well as his description of specific unmanned aircraft capabilities, provide a foundation for analysis that may influence the future employment of military rotary-wing unmanned aircraft.

Another study conducted at the Air Force Institute of Technology by Major Jason T. Williams, U.S. Air Force, describes 11 customer criteria that are "extremely important" to rotary-wing unmanned operations supporting tactical logistics. These 11 criteria include: day and night operating capability, all-weather capability, ability to land in a confined area, speed of delivery, low maintenance needs, mission endurance, ability

⁹Ibid., 5.

to carry a wounded individual, load capacity greater than 2,000 pounds, low noise signature, mission range, and autonomy. These criteria not only define the numerous capabilities of an unmanned rotary-wing cargo aircraft, but also offer major tactical advantages to the ground force commander.¹⁰ Williams utilized these customer criteria to emphasize the multiple capability areas cargo unmanned aircraft can impact. These customer criteria correlate to tactical logistics mission tasks in support of joint operations.

United States Marine Corps

The U.S. Marine Corps has found success using unmanned rotary-wing aircraft for tactical resupply and cargo missions. For example, in Afghanistan they have successfully employed Lockheed Martin's K-MAX rotary unmanned aircraft.¹¹ The K-MAX is a dual rotor unmanned aircraft remotely piloted to land and take-off, but is programmed and controlled through the use of line-of-sight signals to fly a route autonomously. The K-MAX is able to externally carry 6,000 pounds of cargo from one forward operating base to another and can provide critical supplies to Marines on the battlefield without putting aircrew members in harm's way.

This literary review had determined the most recent examples of rotary-wing unmanned research have focused on the aircraft capabilities but offered little insight on their effects in tactical logistics missions. Both rotary-and fixed-wing unmanned aircraft

¹⁰Major Jason Williams, "Tactical Unmanned Airlift: A Business Case Study" (Graduate Research Project, Air Force Institute of Technology, Wright-Patterson AFB, OH, 2010), 60.

¹¹Mike McCarthy, "Unmanned Cargo Helicopter shows Sustainability in Test," *Defense Daily* 251, September 6, 2011, <http://search.proquest.com/docview/899263700?accountid=28992> (accessed April 3, 2013), 1.

have successfully performed attack and reconnaissance missions but there are only a few cases of successful unmanned cargo rotary-wing aircraft. Therefore, the U.S. Marine Corps research and testing of unmanned rotary-wing aircraft in support of tactical logistics missions serves as a prime case study for this thesis.

United States Navy

The U.S. Navy deployed one of the first rotary-wing unmanned aircraft to support tactical maritime missions. The MQ-8B Fire Scout, manufactured by Northrop Grumman, is a fully autonomous rotary-wing unmanned aircraft the U.S. Navy has used since 2008. These aircraft provide real-time full motion videos, intelligence gathering, communications relay capability, precision targeting, and battle damage assessments for the ship commander.¹² Additionally, through the use of its sensors, the MQ-8B Fire Scout is capable of providing Littoral Combat Ships with situational awareness and precision strike capabilities to facilitate open shipping lanes in international waters, as well as deter and fight piracy off the coastlines of nations fundamental to U.S. national interests.¹³ Recently, and most pertinent to this research study, the Navy has experimented with cargo resupply missions using the Fire Scout. This is the Navy's attempt to utilize the Fire Scout to move cargo from one ship to another and could provide important information to this study.

¹²John McHale, "Sensitive and Tireless, High Endurance UAVs Sense What Humans Cannot," *Military and Aerospace Electronics*, April 2007, <http://www.militaryaerospace.com/articles/print/volume-18/issue-4/features/special-report/sensitive-and-tireless-high-endurance-uavs-sense-what-men-cannot.html> (accessed July 12, 2013), 38.

¹³R. Braybook, "Practical Lessons...and Remedies," *Armada International* 33, no. 3 (June 2009): 10.

United States Army

The U.S. Army first became interested in unmanned rotary-wing aircraft in 2004 and established the Unmanned Combat Armed Rotorcraft (UCAR) program.¹⁴ Both Northrop Grumman and Kaman were the lead contractors for the unmanned rotary prototype. The UCAR was designed to be an autonomous strike aircraft that could conduct the deep strike into enemy territory to destroy high value targets, much like the AH-64 Apache was designed to do.¹⁵ More recently, largely due to the insurgencies in Iraq and Afghanistan, the U.S. Army has shifted its focus to fixed-wing unmanned aircraft. However, the U.S. Navy and Marine Corps have continued to exploit their contracts from Northrop Grumman and Kaman, and have developed and used what are now the MQ-8D Fire Scout and the K-MAX.

In 2007, the U.S. House of Representatives reported that the U.S. Army was leveraging the success of the U.S. Navy's Fire Scout program and would begin testing and developing an almost identical version of the Navy's Fire Scout in early 2008.¹⁶ The point of the Army's Fire Scout program was to utilize the same aircraft and save money, but the program was contingent upon the success of the Future Combat Systems program.

¹⁴“Three D Mission—Dull, Dirty and Dangerous,” *Armanda International* (January 2004): 16.

¹⁵*Ibid.*

¹⁶United States Congress, Committee on Armed Services. Subcommmette on Air and Land Forces, *Hearing on National Defense Authorization Act for Fiscal Year 2008 and Oversight of Previously Authorized Programs Before the Committee on Armed Services, House of Representatives, One Hundred Tenth Congress, First Session: Air and Land Forces Subcommittee Hearing on Budget Request on Unmanned Aerial Vehicles (UAV) and Intelligence, Surveillance, and Reconnaissance (ISR) Capabilities, Hearing Held* (Washington, DC: Goverment Printing Office, April 19, 2007), 52.

The Future Combat Systems program was the U.S Army's attempt to modernize their ground and air vehicles that included the failed RAH-66 Comanche Helicopter program. The Future Combat Systems program failed in 2009, and so did the Army Fire Scout program.¹⁷

In 2012, the U.S. Army began looking again for an autonomous unmanned rotary-wing aircraft prototype, specifically the K-MAX and another called the A-160 Hummingbird.¹⁸ The A-160 Hummingbird is designed to conduct aerial intelligence, surveillance, and reconnaissance (ISR) missions, fly 12-hour missions, and provide a platform that utilizes a radar system that can spot, mark, and target human activity through tree canopy.¹⁹ Originally, the Army's interest in the new A-160 Hummingbird was for cargo lift capabilities, but it has since shifted its interests to tactical ISR capabilities. The Hummingbird still remains one of the top options for development in support of tactical logistics missions. However, acquisition has been slow because of government fiscal issues and the rapidly changing operational environment.²⁰ Compared to the U.S. Marines Corps and U.S. Navy, the U.S. Army's search for a viable unmanned cargo rotary-wing aircraft is significantly behind.

¹⁷Brian Robinson, "FCS Cancellation Confirmed, Army Modernization Changes Course: Several Smaller Programs to take the place of Futer Combat Systems," *FCW: The Business of Federal Technology*, June 24, 2009, <http://fcw.com/articles/2009/06/24/army-future-after-fcs.aspx> (accessed August 2, 2013).

¹⁸"Army Shows interest in the KMAX," *Helicopter News*, January 17, 2012, 1-2.

¹⁹Thomas Withington, "Synthetic View of Drones," *Armada International* (June 2008): 40.

²⁰Paul McLeay, "US Army Takes it Slow on Cargo UAV Program," *Defense News*, April 6, 2012, <http://www.defensenews.com/article/20120406/DEFREG02/304060003/U-S-Army-Takes-Slow-Cargo-UAV-Program> (accessed July 12, 2013).

Since the use of unmanned aircraft was first publicized, an increasing number of articles have described the positive effects that unmanned aircraft have on the battlefield. The influences of fixed-wing unmanned aircraft have led to significant organizational changes in the U.S. Air Force and, to a lesser extent, the U.S. Army, which has predominantly flown manned aircraft. Yet recently, the Army outfitted its Aerial Reconnaissance Squadrons with a fixed-wing unmanned aircraft troop or company, and is in the market for an autonomous cargo unmanned rotary-wing aircraft to support logistical movements.²¹ Although the U.S. Army has only seen minor changes to its organization because of the introduction of tactical unmanned fixed-wing aircraft, it is possible they will experience even more change when incorporation of unmanned rotary-wing aircraft peaks. Because the U.S. Army is primarily rotary-wing equipped, it will experience large impacts to its tactical troop and company formations, much as the U.S. Air Force has experienced as it has downsized its precision strike aircraft in favor of unmanned aircraft capabilities over the last 10 years. If the cargo unmanned rotary-wing concept positively impacts tactical resupply missions, major organizational changes will occur in the U.S. Army utility and lift rotary-wing community, which is the largest population of helicopters in its Combat Aviation Brigades.

Coalition Partners

Other U.S. allies and potential partners in a multi-national coalition, such as Great Britain, Switzerland, Israel, Spain, and Ecuador, have explored advanced unmanned

²¹Stephen Trimble, "US Army Launches Hunt for Autonomous Cargo Aircraft," *Flight International*, 24 January 2012, <http://www.docstoc.com/docs/160108328/Flight-International-2012-01-24> (accessed April 1, 2013), 1.

rotary-wing aircraft. For example, Israel, Spain, and Ecuador have purchased rotary-wing unmanned aircraft with synthetic aperture radar for high-resolution analysis of terrain. Israel and Ecuador have purchased a rotary-wing unmanned aircraft for land and maritime use, while Spain plans to develop a fixed and rotary-wing hybrid unmanned aircraft for overland use.²² However, these three countries have relatively underdeveloped unmanned rotary and fixed-wing developmental programs and have yet to explore the possibilities of unmanned rotary-wing support to logistics. Other countries, like Great Britain and Switzerland have entertained the idea of unmanned rotary-wing support to logistics. Great Britain has provided research and vignettes outlining the benefits of rotary-wing unmanned aircraft support to logistics.²³ They describe a future battle space in a notional failed state in which operations would rely heavily on air or overland resupply by airdrop or mobile unmanned rotary aircraft because of the threat of roadside bombs. Though Great Britain does not have a current concept, it recognized the need for unmanned rotary-wing resupply in their doctrine. Another ally, Switzerland, has explored rotary-wing unmanned aircraft for a variety of homeland missions, including the cargo lift capability to resupply stranded hikers in the mountainous Swiss terrain during harsh weather conditions. In a recent Swiss article, four unmanned rotary-wing aircraft were showcased. One of these, the SKELDAR V200, was capable of carrying small amounts of cargo and payload.²⁴

²²Withington, "Synthetic View of Drones," 38-40.

²³Development, Concepts and Doctrine Centre, *The UK Approach to Unmanned Aircraft Systems*, 7-1.

²⁴"VTOL UAS: Vertical Take-off and Landing Unmanned Aerial System," Advertisement Brochure, Swiss UAV, 2011.

As unmanned aircraft popularity grows in other nations, the Department of the Army should reference allied lessons learned to improve their programs. Furthermore, the Department of the Army should continue to understand the capabilities that international partners can provide to the coalition battle.

Defense Advanced Research Projects Agency

The majority of the unmanned aircraft introduced in the Department of Defense and in use by our coalition partners originated in the Defense Advanced Research Projects Agency (DARPA). DARPA's first experimentation with unmanned rotary-winged aircraft began in the 1960s when they developed a QH-50 Drone Anti-Submarine Helicopter to attack submarines better and further than anti-submarine torpedoes at that time.²⁵ Later, DARPA tested other unmanned rotary-aircraft like the X-50 Dragonfly that possessed the potential for lift, logistical support, and attack missions.²⁶ DARPA focused its research and development efforts toward the fixed-wing intelligence, surveillance, and reconnaissance gathering during the Iraq and Afghanistan insurgencies, but continued to develop a need for a high altitude cargo carrying unmanned helicopter like the A-160T Hummingbird. Although the Hummingbird has been considered and passed over multiple times by the Army, it possesses a robust list of capabilities and is quite possibly the best airframe to support tactical logistics missions. DARPA aims to improve the

²⁵Mike Hirschberg, "DARPA's Legacy Takes Flight: Contribution to Aeronautics," http://websearch.darpa.mil/search?q=takes%20flight&btnG=Search&entqr=0&ud=1&sort=date:D:L:d1&output=xml_no_dtd&oe=UTF-8&ie=UTF-8&client=default_frontend&proxystylesheet=default_frontend&site=default_collection (accessed July 14, 2013), 141.

²⁶Major Robert Glenn Wegner, "A Pilotless Army in the Megalopolis" (Monograph, School of Advanced Military Studies, Fort Leavenworth, KS, 2004), 54.

Hummingbird so that it can reach altitudes of 30,000 feet and maintain flight endurance for 30 hours.²⁷ In terms of tactical lift missions this translates into an unmanned rotary-wing aircraft that can carry more cargo for tactical resupply.

Opposition to Cargo Unmanned Aircraft

In the U.S. Army sustainment and logistics community, some logisticians have adverse opinions about unmanned aircraft support to logistics operations. In his article, “A Case Against an Unmanned Cargo Aerial System,” Captain Ben Betson explains many considerations regarding the use of unmanned rotary-wing aircraft to provide tactical logistics support. Specifically, Betson discusses the advantages of unmanned cargo aircraft including putting fewer people in harm’s way, navigating difficult terrain, and relying less on ground convoys. Betson also discusses major disadvantages such as heavy maintenance costs, centralized execution, and small cargo lift capability.²⁸ However, Betson’s study does not account for some critical criteria like response time, performance in adverse weather, and performance in low illumination, which Williams’ study discusses. Furthermore, other articles dispute Betson’s views on the cost of maintenance for unmanned rotary-wing aircraft, arguing that unmanned rotary-wing aircraft are cheaper to maintain than manned rotary-wing aircraft. Overall, while this article was a good synopsis of the cargo unmanned rotary-wing aircraft situation in the U.S. Army, it lacked the detail and analysis that other studies have included.

²⁷Hirschberg, “DARPA’s Legacy Takes Flight,” 150.

²⁸Captain Ben Betson, “A Case Against an Unmanned Cargo Aerial System,” *Army Sustainment* 44, no. 5 (September-October 2012): 1.

Summary

This literature review identifies gaps in previous studies in this subject. The U.S. Army's lack of research on the topic of unmanned rotary-wing aircraft is the most significant research gap prevalent to this thesis. This thesis will provide analysis and synthesis of these gaps in literature. The research methodology will help emphasize and compare these literature gaps that previous research was unable to cover.

The next chapter will describe the research methodology of this study. The research methodology focuses on answering the primary and secondary research questions of this thesis. It compares unmanned rotary-wing aircraft to manned rotary-wing aircraft and the advantages and disadvantages each system provides to tactical logistics missions in support of joint operations.

CHAPTER 3

METHODOLOGY

The purpose of this thesis is to research rotary-wing unmanned aircraft, compare manned rotary-wing platforms versus unmanned rotary-wing aircraft against 11 evaluation criteria, and evaluate the costs and benefits both have on tactical logistics missions in support of joint operations.

Evaluation Criteria

The research methodology evaluates manned and unmanned rotary-wing aircraft against the 11 criteria referenced in Major Jason Williams' case study conducted in 2010. The 11 criteria he used were based on a 2010 General Dynamics customer needs survey and study developed during the engineering of a cargo-unmanned aircraft. The 11 criteria they determined from the research are day and night operating capability, all-weather capability, ability to land in a confined area, speed of delivery, low maintenance needs, mission endurance, ability to carry a wounded individual, load capacity greater than 2,000 pounds, low noise signature, mission range, and autonomy in an unmanned rotary-wing aircraft in support of a cargo lift mission.²⁹

In this study, when comparing both manned and unmanned rotary-wing aircraft against the evaluation criteria, the resulting outcome will be the cost or benefit that either system provides in terms of the criteria. The importance of the comparison is “why” the criteria are important to the customer. For example, why is autonomy an important aircraft capability? Answering this question begins with an understanding of the

²⁹Williams, “Tactical Unmanned Airlift: A Business Case Study,” 60.

evaluating criteria as it applies to the broader engineering design. That is, from a design perspective, autonomy means an aircraft can fly by itself with just electronic, computer control and, without a pilot or remote pilot required to operate it. The benefit to the customer is the savings in the cost to train pilots, either remotely or in the aircraft, and to maintain their proficiency. However, while the cost benefits based on aircraft design are important, they do not reflect the specific benefits that may pertain to their employment in tactical logistics missions. To more narrowly identify the potential benefits in this specific area of interest, this study will apply the evaluation criteria to determine the benefit each criterion provides to tactical logistics in support of joint operations.

Method

The research methodology consisted of two steps. First, it defined the cost or benefit each of the 11 criteria has on tactical logistics in support of joint operations. Second, it determined which aircraft system, manned or unmanned rotary-wing, is best suited to provide the logistical benefits described in the first step. The results of this methodology answered the primary and secondary research questions and identified which criteria affected tactical logistics most. Conclusions based on these results helped to formulate the recommendations for the Department of the Army as to which rotary-wing platform can effectively conduct tactical resupply in support of joint logistics.

The next chapter will apply the research methodology described in this chapter to analyze the 11 criteria and their effects on tactical logistics in support of joint operations. The methodology utilizes past research papers, books, articles, historical case studies, and theoretical vignettes described in the literature review.

CHAPTER 4

ANALYSIS

The purpose of this thesis is to research rotary-wing manned and unmanned aircraft, evaluate the costs and benefits both have on tactical logistics in support of joint operations, and compare manned aircraft versus unmanned aircraft against the three most important evaluation criteria.

To understand which aircraft is more beneficial to tactical logistics in joint operations, the costs and benefits relating to tactical logistics were compared using 11 evaluation criteria. Aside from manned or unmanned aircraft, the criterion describes important details and their overall advantages and disadvantages to tactical logistics. The final analysis of this study narrows the 11 evaluation criteria to the three most pertinent criteria to tactical logistics missions. The top three criteria were chosen based on the greatest potential to fill a known capability gap in tactical logistics missions. This section provides more examples and detail of the three criteria and the reason they impact tactical logistics missions more than the other eight criteria. The results indicate the top three criteria as: operations in degraded visual conditions, low maintenance need, and autonomy.

Eleven Evaluation Criteria

Ability to Carry a Wounded Soldier

Manned or unmanned aircraft's ability to carry a wounded soldier criterion is outside the scope of this study. Air medical evacuation missions do not directly relate to tactical logistics missions. Further research may determine that medical evacuation missions could benefit from unmanned rotary-wing aircraft capabilities.

Load Capacity Greater than 2,000 Pounds

Load capacity of a particular aircraft depends on engine characteristics and strength of the structural airframe. These two qualities either reduce or increase the payload carrying capability of an aircraft in tactical logistics missions. Larger aircraft payload is advantageous in combat environments because it reduces enemy exposure time to the aircraft and its crew while maximizing the amount of supplies to the ground force. The importance of this criterion is the aircraft's capacity to consistently provide the customer's payload of 2,000 pounds based on most conditions. To meet this requirement, engineers have designed airframes and engines capable of supporting the desired customer payload.

Ability to Land in Confined Areas

Rotary-wing aircraft's most unique capability is its ability to conduct confined area landings because it can maintain a hover and maneuver in all directions. Pilot skill and the physical size of the airframe to include the rotor systems are the main limitations during confined area landings. The ability to land in a confined area is important because tactical logistics missions require precise and accurate delivery. Rotary-wing aircraft have demonstrated sufficient accuracy under most conditions to indicate that they can provide this service in military operations. Although it is not always possible to land in the precise troop location due to unsuitable landing areas, certain techniques can assist in confined areas that preclude landing. Techniques such as a low hover, external sling load configuration, or parachute drops can overcome these circumstances in manned and unmanned rotary-wing aircraft.

Speed of Delivery

Speed of delivery is important to tactical logistics because it determines the response time for planning and reacting to unanticipated supply missions. The speed of delivery maximizes flexibility and gives the ground force more rapid resupply.

Conversely, aircraft speed is near negligible for routine logistics missions because effective planning eliminates the need for a quick response time. Engine strength and aircraft aerodynamics are key technical components of this criteria that define planning airspeeds for both routine and urgent logistics missions.

Low Noise Capacity

Noise capacity can disrupt tactical logistics missions in support of joint operations. For example, aircraft noise gives the enemy a general direction of friendly force locations and places aircraft at risk to enemy weapons systems. The low noise capacity or noise signature of an aircraft directly impacts its survivability, which is “the capability of a system to avoid or withstand manmade hostile environments without suffering an abortive impairment of its ability to accomplish its designated mission.”³⁰ Essentially, a low noise signature allows the aircraft to maneuver in contested areas undetected by the enemy even when traveling at slower low-level and approach airspeeds. Modifying the engine or the rotor blades are two ways to reduce the noise level of a rotary-wing aircraft but could reduce engine power and blade lifting capabilities as well. Neither manned nor unmanned rotary-wing aircraft has a major advantage in this aspect.

³⁰United States Army, Army Regulation (AR)70-75, *Survivability of Army Personnel and Material* (Washington, DC: Government Printing Office, May 2005), 16.

Mission Range

Mission range is a key planning factor for sustained tactical operations and directly relates to tactical logistics by affecting how deep into enemy territory the ground force is able to extend supply lines. An effective plan factors in aircraft capabilities to determine a constant supply rate to the ground force and the maximum range they can travel before outrunning their supply lines. Mission range is the maximum distance a unit is able to operate away from its logistical hub and aircraft maximum range is its key component. Aircraft maximum range airspeed is defined as the optimal airspeed to fly the aircraft the furthest distance.³¹ The extended mission range gained by aircraft logistics capabilities directly benefits ground forces. Urgent logistics missions benefit most from an aircraft with an extended mission range capability because of the limited mission planning time associated with it.

Mission Endurance

Mission endurance has many similar characteristics as the mission range criteria previously described. The U.S. Army Aviation's *Fundamentals of Flight* defines it, "Maximum Endurance airspeed is an airspeed that allows the helicopter to remain flying the most amount of time."³² In terms of tactical logistics, this criterion is the amount of time a ground force can expect to have an aircraft airborne for a mission. The aircraft may loiter waiting for a mission to occur or continuously fly supplies back and forth from the main supply hub to the ground force. Aircraft characteristics determine mission

³¹United States Army, Field Manual (FM) 3-04.203, *Fundamentals of Flight* (Washington, DC: Government Print Office, May 2007), 1-24.

³²Ibid.

endurance and are quantifiable for planning and executing successful tactical logistics missions.

Day and Night Operating Capability

Day military operations, to include rotary-wing operations, are less complicated than night operations. Therefore, discounting risks associated with visual targeting, missions conducted at night can also be accomplished during the day. Because darkness degrades vision, causing slower more calculated movements, this section focuses only on night operations in support of tactical logistics missions.

Soldiers gain the advantage of surprise over the enemy if they can operate military equipment and vehicles, to include manned and unmanned aircraft, during low illumination nighttime operations. Army Publication, Field Manual 3-04.203, *Fundamentals of Flight* discusses the importance of illumination or ambient light and the many factors that affect it. Sources of ambient light include the moon, background illumination, artificial light, and solar light, but are affected by clouds, mountains, buildings, and other meteorological conditions.³³

For the purpose of this study night operations are aviation operations that occur with the aid of night vision devices commonly known as night vision goggles (NVGs). The day and night operating capability criterion is important to this study because it defines the aircraft's ability to perform tactical logistics missions in low illumination. Low celestial or civil light conditions are a major limitation to night operations in military aviation because NVGs must have a minimum amount of moon or star lighting

³³Ibid., 4-3.

to artificially multiply light sufficiently to be visible to the human eye. Once NVGs amplify the natural light from the moon, stars, or streetlights in a populated area, the human eye can detect various shades, intensities, and shadows in, on, and around different objects and obstacles. However, if moon, stars, or street lighting is low or does not exist, then night vision devices cannot produce artificial light in these conditions.

Unmanned rotary-wing aircraft overcome NVG limitations and help avoid accidents associated with them. Every year the Army has a manned helicopter accident in low illumination or bad weather resulting in fatalities.³⁴ Low illumination conditions are a major contributor to pilot spatial disorientation, which constitutes a loss in aircraft awareness. A recent study from the U.S. Army Aeromedical Research Laboratory shows that 44 percent of spatial disorientation accidents occur using NVGs.³⁵ As a result, the Army either cancels these missions or places crewmembers in dangerous situations. There is an inherent risk to rotary-wing crewmembers that comes with NVG operations in low illumination situations that can be avoided with the support of unmanned rotary-wing aircraft.

The ability of manned or unmanned rotary-wing aircraft to support tactical logistics missions under low illumination conditions introduces a critical capability to the ground force commander. The commander can respond to any emergency under this

³⁴Kevin M. Allen, "Army Air Crews," September 15, 2013, www.armyaircrews.com (accessed October 25, 2013).

³⁵Steven J. Gaydos, M. J. Harrigan, and Alaistair J. R. Bushby, *Ten Years of Spatial Disorientation in U.S. Army Rotary-Wing Operations* (Reprint) (Fort Rucker, AL: Department of the Army, U.S. Army Aeromedical Research Laboratory, October 2012).

condition with confidence that the element on the ground will receive the necessary supplies.

All Weather Capability

Aviation operations are often restricted by meteorological conditions such as low cloud ceilings and reduced ground visibility. For this study, the all-weather capability criterion pertains to the aircraft's ability to complete a tactical logistics mission unimpeded by low cloud levels or visibility restrictions.

Low cloud cover conditions, or low ceilings, pose several risks to rotary-wing crewmembers in tactical logistics missions. The first risk is the potential for unplanned visual loss of the ground or physical horizon without the possibility of regaining it with the help of instrument navigational aids. In Army aviation this is defined as Inadvertent Instrument Meteorological Conditions (IIMC), in which a pilot is forced to fly the aircraft by instrumentation only due to inclement weather, but did not plan for it.³⁶ If untrained, this can result in fatal rotary-wing accidents. The second risk is low ceilings that restrict crewmembers from determining the terrain at normal cruise speeds. Aircrews are less likely to see obstacles like wires, towers, mountains, or other flying objects at higher airspeeds because low ceilings limit their visual cues from a higher angle in the air, thus decreasing the aircrew's reaction time to spot, acknowledge, and avoid obstacles. Reducing the airspeed of the aircraft helps increase reaction time, but poses another risk to the crew and aircraft in combat operations. The third risk is slow flying aircraft at low

³⁶United States Department of Transportation, Federal Aviation Administration, *Instrument Procedures Handbook*, Vol. FAA-H-8261-1a (Washington, DC: Government Printing Office, 2007), 7-17.

altitude in potentially high enemy threat areas. The odds of targeting and hitting a flying aircraft are difficult with small arms fire, but low altitudes and airspeeds increase the enemy's chances.

Restricted visibility from fog, smoke, or dust typically hinders rotary-wing operations for some of the same reasons low cloud ceilings do. Low visibility conditions also intermittently restrict visual contact of the ground or physical horizon. The denser the conditions are, the more they restrict the pilot's view. The longer these conditions exist, the more likely the pilot will lose site of the ground or physical horizon or become spatially disoriented. Spatial disorientation is the inability of the pilot to judge his or her attitude, altitude, and airspeed while flying.³⁷ When the pilot becomes spatially disoriented, he or she loses awareness of the aircraft's actual position in the air and can no longer operate the aircraft safely. This is also conducive to IIMC conditions as previously discussed. Restricted visibility also decreases crew reaction time to obstacles or terrain and may force the crew to reduce airspeeds to avoid striking them. Airspeed reduction also makes the crew and aircraft vulnerable to enemy weapon systems although low visibility may reduce the likelihood of being spotted by the enemy. Restricted visibility can span small areas like ponds or rivers or major terrain features like an entire valley or desert floor.

The importance of an all-weather capable aircraft criterion to tactical logistics is having the ability to fly during restricted visibility caused by poor weather conditions. When restricted visibility precludes the safe operation of manned aircraft, the ground

³⁷United States Army, Training Circular 3-04.93, *Aeromedical Training for Flight Personnel* (Washington, DC: Government Printing Office, August 2009), 9-1.

force may not be able to receive resupply for an extended period of time. Unmanned rotary-wing aircraft can potentially fill this capability gap.

Low Maintenance Need

The common variables that define a low maintenance need are the duration of the military operation and the amount of man-hours it takes to maintain the aircraft. The first variable influences the second in the maintenance and budgetary processes. This study will explore these two variables and how to reduce maintenance need and cost to support tactical logistics missions.

The Army manual for cargo and utility helicopter regulations defines maintenance as a combat multiplier and a key component to maintaining an advantage over the enemy for an extended amount of time.³⁸ More importantly, offering quality maintenance at low cost to the taxpayer helps fund extended military operations and campaigns. The *Cargo and Utility Helicopter Operations* manual further elaborates on the importance of maintenance to combat operations over long periods of time—

When enemy forces have relative parity in numbers and quality of equipment, the force combining skillful use of equipment with an effective maintenance system has a decisive advantage. This force has an initial advantage in that it enters battle with equipment likely to remain in operation longer. A subsequent advantage is that it can repair damaged equipment, make it operational, and return the equipment to the battle faster.³⁹

³⁸United States Army, Field Manual (FM) 3-04.113, *Cargo and Utility Helicopter Operations* (Washington, DC: Government Printing Office, December 2007), 4-6.

³⁹*Ibid.*

Affordable maintenance not only utilizes the defense budget more efficiently, but also influences the policy makers approving the budget. Both reasons are conducive to enduring military operations.

Fixed and rotary-wing aircraft require routine maintenance based on hours of operation to comply with safety standards. However, aviation maintenance operations are tedious and require a significant amount of manpower. To help overcome the demands, Army aviation maintenance deliberately plans for aircraft maintenance operations in austere environments. The cargo and utility helicopter manual discusses this approach:

Aviation maintenance is performed on a 24-hour basis. The governing concept is to replace forward and repair rearward so units can rapidly return aircraft for operational needs. Emphasis is on component replacement rather than repair. Such replacement requires increased stockage of line replaceable units (LRUs) and quick-change assemblies. Damaged or inoperable aircraft requiring time-consuming repair actions are handled in more secure areas toward the rear.⁴⁰

Planning maintenance requires not only an understanding of manpower demands, but also an understanding of the entire enterprise to include the maintenance infrastructure.

Maintaining both fixed or rotary-wing aircraft requires special facilities, large equipment, and specialized tools. In austere conditions, maintainers are able to execute only routine maintenance tasks, creating challenges in stationing and organizing aviation units in deployed areas. More sophisticated aircraft require more sophisticated maintenance processes and facilities. Often the maintenance infrastructure established in the area of operation is unable to support the demands of overly sophisticated aircraft.

Low maintenance characteristics are important because it has the most potential for reducing the overall cost of continuous rotary-wing operations in tactical logistics

⁴⁰Ibid., 4-7.

missions. This study compares manned and unmanned rotary-wing aircraft maintenance operations in austere areas and the associated costs to support both. It focuses on potential unmanned rotary-wing maintenance needs in these environments and whether current maintenance infrastructures can support existing cargo rotary-wing unmanned aircraft.

Autonomy

Autonomy refers to the aircraft's ability to operate, through computer or robotic systems, independent of human control.⁴¹ This term and definition imply that manned aircraft cannot be autonomous but that is incorrect. Most modern aircraft possess autonomous technology because of the invention of autopilot. An autopilot computer system controls and flies an aircraft, yet a human pilot in the aircraft monitors it closely. Depending on the sophistication of the autopilot system, once airborne, it can fly a route and enter an approach thousands of miles away before a pilot has to intervene. Remotely piloted aircraft operate in a similar manner where a pilot is not physically in the aircraft but in a ground station. The unmanned aircraft has autonomous capabilities much like the manned aircraft's autopilot system. Unmanned aircraft typically have an autonomous capability in the event the satellite link is lost between the pilot station and the unmanned aircraft. This system allows the unmanned aircraft, once satellite communications are lost, to sense the lost link and return autonomously to its home station. Autonomous

⁴¹United States Army Aviation Center of Excellence, *US Army Unmanned Aircraft Systems Roadmap 2010-2035* (Fort Rucker, AL: United States Army, 2010). 113.

capabilities are becoming more prevalent in manned and unmanned aircraft as technology advances.

Despite the increasing sophistication of aircraft flight systems, no aircraft has total autonomous capabilities. Total autonomy would mean that an aircraft could launch, conduct its mission, and recover without ever being monitored by a human being. The U.S. Army has recently defined autonomy levels that describe the degree of robotic control over aircraft and human monitoring.⁴² Some aircraft may require a soldier to launch, fly, and land the aircraft, while others, like the K-MAX Burro and A-160T Hummingbird, only require a human to launch and recover the aircraft and provide minimal in-flight monitoring.⁴³

Autonomous capabilities reduce pilot workload in stressful, task-saturated environments. Manned aircraft rely on autopilot to assist the pilot with simple flying tasks during more complex missions. Autopilot allows them to maintain better situational awareness outside the aircraft. For example, an AH-64 pilot and co-pilot following a human target have many requirements, such as maintaining visual contact with the target, reporting the target to the higher headquarters, informing the ground force of the target's intentions, maintaining airspace control, maintaining its own security and, if required, firing lethal effects at the target. The AH-64 crew's most important responsibility is to maintain aircraft control assisted by the aircraft's autonomous capabilities.

⁴²Ibid., 114.

⁴³Staff Defense Industry Daily, "Unmanned Hellos: The USMC's Unmanned Cargo Helicopters," *Defense Industry Daily*, March 27, 2013, <http://www.defenseindustrydaily.com/USMC-Looks-for-an-Unmanned-Cargo-Helicopter-06672/> (accessed October 1, 2013).

While manned aircraft rely heavily on autonomous capabilities for aircrew workload management, unmanned aircraft rely on these capabilities even more for mission accomplishment. The lost link scenario is important to aircraft safety and survivability, and it improves aircraft capabilities in other scenarios as well. One important aspect for unmanned aircraft is the pilot to aircraft ratio. In remotely piloted aircraft, with the help of autonomous technology, it is possible for an operator to fly more than one aircraft at one time. The Air Force recently proposed that one pilot could operate up to eight unmanned fixed-wing aircraft with autonomous technology.⁴⁴ This would reduce the pilot's monitoring of aircraft while in-transit. Basically, pilots would not monitor aircraft while in-transit; instead the computer system would maintain safe control and airspace deconfliction. This capability could prove to be a combat multiplier in future unmanned operations for all services.

In its many diverse mission sets, tactical logistics could benefit greatly from a more autonomous aviation force. In addition to the benefits of reduced manpower, autonomy provides tactical advantages, such as landing in degraded visual environments. Currently, even the best remote operator with the best full motion video technology cannot land in degraded visual conditions. For example, if the ground force determines there is a suitable landing zone for an aircraft with set size, that aircraft could fly a route guided by satellite global position system (GPS) technology, hover over the grid location, and drop supplies from a safe height to the ground force. In this scenario, at no time would the aircraft have to see the terrain or the landing zone as long as it is above

⁴⁴United States Air Force, *Air Force Unmanned Aerial System (UAS) Flight Plan 2009-2047* (Washington, DC: United States Air Force Deputy Chief of Staff, Intelligence, Surveillance, and Reconnaissance, July 23, 2009).

obstacles. Smoke, fog, dust, snow, or haze could obstruct the terrain around the landing zone, but the autonomously capable aircraft could execute the resupply. This technology has only undergone limited testing, but if proven reliable, could result in groundbreaking impacts on tactical logistics missions by unmanned rotary-wing aircraft.

Narrowed Criteria

This section describes in further detail the three criteria, of the 11 evaluated, that most significantly impact tactical logistics operations: capability in degraded visual conditions, low maintenance need, and autonomy. These three criteria were chosen because they fill a critical capability gap in tactical logistics missions in support of joint operations. They also allow the ground force commander to conduct missions continuously and maximize flexibility in his or her operational plan. The other criteria either had negligible or minimal impact on tactical logistics when comparing manned and unmanned aircraft or did not pertain to this study. This section discusses the capability needed for the top three criteria in unmanned rotary-wing aircraft specific, to tactical logistics missions.

Table 1 outlines all 11 criteria, describes their relevance to this study, and the logic used to determine the top three criteria. The chart describes whether an unmanned rotary-wing aircraft has a capability advantage over a manned rotary-wing aircraft with respect to a criterion and then determines its general level of application to tactical logistics missions.

Table 1. Evaluating Criteria

Criteria	Capability Advantage	Application to Tactical Logistics
Ability to Carry a Wounded Soldier	No	Irrelevant
Load Capacity Greater than 2,000 Pounds	No	Negligible
Ability to Land in Confined Areas	No	Negligible
Speed of Delivery	Yes	Negligible
Low Noise Capacity	No	Negligible
Mission Range	Yes	Negligible
Mission Endurance	Yes	Negligible
Day & Night Operating Capability	Yes	Significant
All Weather Capability	Yes	Significant
Low Maintenance Need	Yes	Significant
Autonomy	Yes	Significant

Source: Created by author.

Capability in Degraded Visual Conditions

Degraded visual conditions significantly impact aerial resupply missions in support of tactical logistics operations. This study evaluates two types of degraded visual conditions: low illumination and poor visibility due to weather. Further defined, degraded visual conditions are conditions lacking a visible horizon from take-off through landing and conditions requiring the pilot to take-off and land the aircraft with systems and instruments. Although degraded visual conditions increase the operational risk for all aircraft, this risk is greater for manned aircraft. Therefore, unmanned rotary-wing aircraft can provide the ground force with more flexible, timely, and low-risk tactical logistics options than manned rotary-wing aircraft.

The ground force relies on resupply, regardless of the environmental conditions. Unmanned aircraft can perform in all conditions and provide more mission flexibility, thus saving time. Time is a major limitation to all missions, including resupply

missions.⁴⁵ Emergency resupply missions depend upon the time it takes the resupply vehicle to reach the resupply point. It is difficult and sometimes impossible to predict the need for resupply. Tactical and operational planning helps predict a time interval through calculation of supply consumption rates and when troops will deplete their food, water, ammunition, and fuel. However, planning cannot predict the number of casualties, maintenance issues, isolated personnel, or mission changes. Often the “friction” of war can stifle many well planned missions.⁴⁶ Aerial resupply in day and night conditions offers even more flexibility by giving the commander a longer operating time. Night operations offer some key benefits over those conducted during daylight hours. The night conceals aircraft from the enemy making night resupply missions less risky to enemy attacks. Night aerial resupply missions also offer a psychological advantage to friendly forces that gain confidence knowing the enemy cannot easily detect their resupply operations.

Flying in total darkness is nearly the same as flying in poor visibility. Aerial operations in low visibility have the same tactical advantages and disadvantages as operating at night. Again, the ground force commander can surprise the enemy and has the flexibility to resupply in disruptive weather conditions. Disruptive weather conditions include extreme heat, cold, rain, snow, dust, and a variety of different storms.⁴⁷ These conditions restrict mobility on roads, wash out bridges, and limit visibility to ground and

⁴⁵United States Army, Field Manual (FM) 4-0, *Sustainment* (Washington, DC: Government Printing Office, April 2009), 3-6.

⁴⁶Carl von Clausewitz, Michael Elliot Howard, and Peter Paret, *On War* (Princeton: Princeton University Press, 2008), 119.

⁴⁷United States Army, Field Manual (FM) 4-0, *Sustainment*, 3-6.

air forces. Weather impacts ground and air resupply missions but less so to the later. Air movement can easily bypass poor conditions that ground forces cannot, such as muddy roads or fallen trees. The U.S. Army currently lacks a capability to expeditiously resupply troops in degraded visual conditions; unmanned aircraft could possibly fill that gap.

The next section of this study will compare the advantages and disadvantages of manned and unmanned rotary-wing aircraft in night and limited visibility conditions. This comparison will analyze the Army's decision to continue to support tactical resupply missions with manned aircraft, as opposed to pursuing unmanned rotary-wing technologies.

The human pilot is the limiting factor during operations of manned aircraft in degraded visual conditions. Systems and instrumentation within the aircraft augment the pilot's visual system, but only under certain conditions. Instrument rated, rotary-wing aircraft typically need an open runway with navigational aids to assist landing in poor weather conditions. NVGs can help rotary-wing pilots land in night tactical environments, confined landing zones, but only with augmented illumination. Instrumentation without navigational aids assists pilots as well, but requires extensive training, confidence, and trust in those systems. For example, the UH-60M and CH-47F hover-hold capability allows a pilot to hover over a specific point free of obstacles, visually or non-visually, and slowly lower it to the ground.⁴⁸ These types of operations could occur in a combat environment, but it is not a quick process and exposes the aircraft to the enemy for an unacceptable length of time.

⁴⁸Frank Colucci, "Digging Out From Brown Out," *Vertiflite* 53, no. 1 (Spring 2007): 50-55.

The ability of the pilot to immediately respond to landing zone conditions is the advantage of manned aircraft. Although unmanned data links between pilot station and aircraft are fast, they still may not adequately respond to rapidly changing conditions. Pilots can react more deliberately to changing winds, terrain, and threat. Thus, the crew and team in manned aircraft may be able to make quicker and better decisions than unmanned platforms.

The disadvantages of performing a hover-hold maneuver to resupply ground forces are increased aircraft exposure time to the enemy and the difficulty of the maneuver. The degraded visual environment could conceal the aircraft, but it is likely the enemy will detect the large size and noise signature. Also, in a non-permissive environment a viable air defense threat with radar detection could shoot down an aircraft in degraded visual conditions. Another challenge, is the difficulty and training of the hover-hold maneuver, by hovering the aircraft to the ground. The concern is the crew still relies on the ground force to identify obstacles in the area and the surface suitability if fully touching down. The ground force's assessment of the landing zone is vital to the success of this maneuver. Finding a GPS point in space is not the difficulty, but hovering vertically over that point without visual references, while maintaining obstacle clearance, requires trust in the ground force's assessment. Moreover, a manned aircraft's capability to conduct a precision landing in degraded visual conditions is possible, but risky to the crew. Ultimately, the crew is placing their lives in the hands of an autonomous aircraft system and ground force assessment, potentially exposing themselves to the enemy and hazardous obstacles in the area.

Unmanned rotary-wing aircraft like the K-MAX can execute resupply missions to unimproved landing zones in degraded visual conditions. Lockheed officials said in a news release following a demonstration at Fort Pickett, Virginia, “Deliveries of cargo as large as a compact car can be placed down with pinpoint accuracy even at night or in harsh weather.”⁴⁹ The K-MAX utilizes external loads or sling loads to deliver supplies to remote areas with precision. The operator simply inputs a digital route and flight plan into the aircraft’s computer software and it executes it from start to finish almost completely autonomously. To pick up the load with an external sling leg, the operator programs the point, hovering altitude, and delay needed for the time it takes to hook up the load. At that point the K-MAX flies the programmed route to the destination, which is marked with a beacon the ground force places on the ground to ensure the load is dropped with precision. The K-MAX accurately drops the load within three meters of the beacon.⁵⁰

As previously described, the unmanned rotary-wing aircraft, specifically the K-MAX, provides many technical advantages to the tactical resupply mission. In almost every technical aspect less cargo load, the K-MAX is as capable, or more so, than the newest manned cargo rotary-wing aircraft, the UH-60M and CH-47F. Most importantly, it has proven it can accomplish the tactical resupply mission in any condition consistently without placing crewmembers in harm’s way. Strategically, utilizing unmanned aircraft

⁴⁹James K. Sanborn, “Beacon Improves UAV’s Cargo-Delivery Accuracy,” *Marine Corps Times*, July 8, 2012, <http://www.marinecorpstimes.com/article/20120708/NEWS/207080314/Beacon-improves-UAV-s-cargo-delivery-accuracy> (accessed October 1, 2013).

⁵⁰*Ibid.*

for timely, routine, and monotonous resupply mission decreases percentages of downed aircraft, isolated personnel, and recovery operations.

In unmanned rotary-wing operations in degraded visual conditions, the advantages outweigh the disadvantages when supporting tactical resupply missions. However, there is one costly strategic disadvantage: losing the aircraft to the enemy. Losing a technologically advanced capability to the enemy affords our adversaries a potential opportunity to reverse engineer our systems, improve them, and possibly employ them against us. Unmanned aircraft that unexpectedly land in enemy territory mostly intact are at greatest risk. Manned aircraft that crash or are forced to land in enemy territory can be destroyed by the crewmembers in worst cases, but often are self-recovered after minor repairs at the scene. Unmanned technology can neither troubleshoot malfunctions nor determine if the situation requires destroying sensitive onboard equipment. Even if unmanned technology could be programmed to self-destruct, other assets have to verify the aircraft's condition. Regardless, both manned and unmanned aircraft risk losing technological secrets to the enemy, but unmanned are most vulnerable. The unmanned aircraft can mitigate some of this risk through its versatility in a degraded visual environment and keeping concealed from the enemy.

Low Maintenance Cost

Ground tactical resupply demands many modes of transportation to include air and ground assets, but each has an associated maintenance cost. It is, quite simply, more cost effective to maintain ground vehicles than sophisticated aircraft. However, poor road networks and increased threats of roadside bombs have forced the military to explore other modes of transportation to deliver supplies. The transportation of choice has been

the cargo utility helicopter. A cargo utility helicopter can move thousands of pounds of supplies at a time but, compared to ground vehicles, aircraft maintenance costs are significantly higher. One solution is to create a system that is not reliant on road networks, can deliver supplies in a timely manner, and is not costly to maintain. The nearest solution appears to be unmanned rotary-wing assets. In many cases, it can be more effective than current ground and manned aircraft systems. This study shows that unmanned rotary-wing aircraft are less expensive compared to manned rotary-wing aircraft, are rarely inhibited by ground conditions, and almost never place the service members at risk.

Manned cargo helicopters have proven they can deliver supplies to the ground force in military and non-military operations, but at the expense of the Department of Defense budget. According to U.S. Congress, the Army allocated nearly \$5 billion in fiscal year 2014 to upgrade and maintain the cargo and utility aircraft fleet.⁵¹ Because the fleet has been recently modernized, they estimate this budget will decrease to \$4 billion in fiscal year 2023. The Army's cargo and utility aircraft fleet is the bulk of the Army aviation inventory, so it could be beneficial to find innovative technologies that reduce overall cost. Unmanned cargo aircraft cost significantly less to build, maintain, and operate. The most disproportionate area of the two programs is the difference in maintenance cost. The total cargo unmanned aircraft budget for fiscal year 2013 was \$105 million for the U.S. Navy.⁵² The U.S. Army estimated its similar program would

⁵¹Department of Defense, *Annual Aviation Inventory and Funding Plan Fiscal Years (FY) 2014-2043* (Washington, DC: Government Printing Office, May 2013).

⁵²Capt. Troy M. Peterson, USMC, and LT. Jason R. Staley, USN, "Case Analysis of Cargo Unmanned Aircraft System (UAS) Capability in Support of Forward Deployed

cost \$51 million in the 2014 budget. The difference in the manned and unmanned budgets is significant, but the U.S. Army does not project financial impacts that increased uses of unmanned rotary-wing aircraft could do to reduce costs in the long term.

A study of cargo utility helicopters calculated operating costs at \$21,919 per flight hour for a cargo unmanned aircraft as compared to \$26,000 per flight hour for a CH-53E.⁵³ The full operational cost includes fuel, manpower, maintenance, risk to life, and risk to platform. In other metrics, it takes 1.6 to 1.9 man-hours to maintain a K-MAX unmanned rotary-wing aircraft for one flight hour compared to 31 man-hours of maintenance for one flight hour in a CH-53E.⁵⁴ Another article compared the direct operation cost of the unmanned K-MAX to the UH-60 Blackhawk. Direct operational cost is similar to full operational cost, except it does not account for risk to crew and platform. In this comparison, the UH-60 Blackhawk costs \$6,400 per flight hour and the K-MAX costs \$1,100 per flight hour.⁵⁵

Many comparisons between the manned and unmanned rotary-wing aircraft identified that unmanned aircraft are significantly cheaper to operate and maintain. The K-MAX has proven it can maintain low maintenance costs while providing high

Logistics in Operation Enduring Freedom (OEF)” (Acquisition Research Sponsored Report, Naval Postgraduate School, Monterey, CA, October 2011), 11.

⁵³Ibid., 33.

⁵⁴United States Marine Corps Center for Lessons Learned, *Air Operations in Support of Logistics* (Quantico, VA: Government Printing Office, 2013), 17.

⁵⁵William Matthews, “Unmanned K-MAX Delivers: USMC Considers ‘Synchropter’ for Cargo Drops in Hostile Terrain,” *Defense News*, February 22, 2010, <http://www.defensenews.com/print/article/20100222/DEFPEAT01/2220311/Unmanned-K-MAX-Delivers> (accessed September 10, 2013).

reliability for the ground force commander's tactical logistics needs. A fleet of K-MAX or similar aircraft could significantly reduce the Army's cargo and utility budget in the coming years. Manned resupply missions augmented with unmanned resupply missions could reduce maintenance man-hours and save money. Cargo and utility helicopters fly the majority of their missions in support of resupply and movement of personnel. If the unmanned rotary-wing aircraft took the burden of resupply missions, the manned aircraft could focus on more direct action missions. The Army conducted a cost benefit analysis of several courses of action and determined that they would augment 30 percent of the manned rotary-wing missions with unmanned platforms.⁵⁶ This course of action was chosen because it was more likely to be implemented than a 100 percent use of unmanned assets. A reasonable assumption for this is the U.S. Army was not prepared for the major impacts that unmanned technology could provide to the resupply and logistics mission. The 100 percent augmentation of manned missions would save the Army \$20 million a year from the status quo.⁵⁷ Instead the Army chose to trim \$51 million in the fiscal year 2014 budgets by cancelling the unmanned rotary-wing program for cargo resupply missions.⁵⁸

The financiers clearly have determined that the low maintenance costs of rotary-wing unmanned aircraft make them financially viable options. Yet, the U.S. Army is still

⁵⁶Peterson and Staley, "Case Analysis of Cargo Unmanned Aircraft System (UAS) Capability in Support of Forward Deployed Logistics in Operation Enduring Freedom (OEF)," 20.

⁵⁷Ibid.

⁵⁸Department of Defense, *Operation and Maintenance Overview Fiscal Year 2014 Budget Estimates* (Washington, DC: Government Printing Office, April 2013), 217.

apprehensive to develop technology that saves money. The K-MAX with a smaller payload has proven in combat that it can complete the same mission as its counterpart, the CH-53E, which is comparable to the Army's CH-47 Chinook lift helicopter. Other factors, such as the debated subject of autonomous technology, may explain the Army's decision to end its unmanned rotary-wing program somewhat prematurely.

Autonomy

Both manned and unmanned aircraft communities value the benefits of autonomous flight capabilities, although with reservations. The manned aircraft community argues that autonomy is beneficial, but requires the oversight of a trained pilot. Pilots manage the aircraft and manipulate the physical controls less often. The unmanned community would not exist without autonomous technology. Remote pilots cannot physically see and feel the aircraft movement, so they rely on the computer system to keep it stable and to recover when the pilot-to-aircraft communication link is lost. Remote pilots do not have to adjust every setting of the aircraft when conditions change. For example, in a rotary-wing aircraft simple adjustments to the path of the main rotor system require the pilot to adjust the pitch, roll, and yaw of the aircraft all at once, which requires the pilot to adjust the collective, pedals, and cyclic to keep the aircraft straight and level. Remotely, pilots adjust the heading while the autonomous system adjusts all the other characteristics to maintain that specific heading. Manned aircraft were the first to implement this technology to reduce the pilot workload, but unmanned aircraft depend upon it. If the digital link between the pilot control station and the unmanned aircraft is lost, problems can occur. There is no fail-safe mechanism invented to back up unmanned systems once their autonomous capabilities fail during lost

communications link. Moreover, Army operators can be categorized as overcautious and do not trust unmanned systems to recover and land themselves autonomously when communication fails. The Department of the Army is primarily risk adverse to autonomous technologies in unmanned rotary-wing aircraft at this time.

The Department of the Army is weary of fully autonomous unmanned rotary-wing aircraft because of immature “sense-and-avoid” technology and their inability to integrate such technologies into the airspace command and control structure.⁵⁹ Sense and avoid technology is being developed to integrate unmanned aircraft into civil airspace, but it applies to aircraft flying in congested combat environments as well. For example, the Army fears it may not be able to recover an armed unmanned aircraft with fully autonomous capability, which could result in a deadly mishap.⁶⁰ This could be the reason that, even in relatively uncongested airspace such as remote outposts in Afghanistan, the Army is untrusting of systems like the K-MAX, despite its ability to autonomously fly and land to a small beacon during routine resupply missions with little pilot input, and without pilot visual references in degraded visual conditions. The acceptance of autonomous technology in unmanned rotary-wing aircraft ultimately fills the capability gap of resupply during degraded visual environments. The KMAX Burro has proven it can do it and its next version will have sense and avoid technology.

⁵⁹Clay Dillow, “Army's Smart 'Sense and Avoid' System Key to Letting Drones Cruise Domestic Skies,” July 9, 2012, <http://www.popsci.com/technology/article/2012-07/armys-new-sense-and-avoid-system-paves-way-drones-domestic-skies> (accessed October 21, 2013).

⁶⁰Carlos Munoz, “The Army Wants a Man in the Loop,” *Breaking Defense*, August 16, 2011, <http://breakingdefense.com/2011/08/army-wants-man-in-the-loop-on-armed-uas-ops/> (accessed October 20, 2013).

Currently, the U.S. Army only allows semi-autonomous systems to operate in congested airspace. Manned aircraft like the UH-60M and CH-47F have semi-autonomous capabilities and their hover-hold function assists the pilot by performing maneuvers in degraded visual environments. The stability and safety of the aircraft rely on the autonomous aircraft's capabilities.⁶¹ However, the hover stabilization system still requires the pilot to operate the hover-hold instrumentation, cross check performance, and possibly override the system. Hover stabilization is not the only autonomous technology in these aircraft. UH-60M and CH-47F aircrafts also use autopilot to help reduce pilot load and fly instrument approaches. Commercial airline pilots have utilized both technologies routinely for many years. Although it is possible to allow the aircraft to land itself from the start of the instrument approach to touchdown on the runway, it is not common. One pilot interview revealed that, "more than 99 percent of approaches are performed manually."⁶² Totally autonomous instrument approaches to the runway require special training, thoroughly tested aircraft instrumentations, and can only be attempted at specific airports. Understandably, it is apparent that both the civilian and military communities utilize autonomous technology, but only on occasion because of the risk to human life. Unmanned aircraft do not have humans aboard, so the risk to human life is significantly lessened, but the Army continues to steer away from the benefits of autonomous technology.

⁶¹Colucci, "Digging Out From Brown Out," 54.

⁶²Melody Kramer, "Q&A With a Pilot: Just How Does Autopilot Work?" *National Geographic Daily News*, July 9, 2013, <http://news.nationalgeographic.com/news/2013/07/130709-planes-autopilot-ask-a-pilot-patrick-smith-flying-asiana/> (accessed October 7, 2013).

Manned and unmanned professionals and operators disagree regarding whether unmanned aircraft should operate in the same airspace as manned aircraft without significant risks to safety. In the U.S. national airspace, it is not yet permissible for unmanned aircraft to fly without a visual airborne or ground observer. In the future, unmanned aircraft may operate without the aid of an observer; however, they will first have to establish a credible safety record of performance. Potentially, unmanned aircraft could collide in mid-air with other aircraft or could crash killing innocent personnel or damage infrastructure on the ground. . . . Technology, to include autonomy, will not solve this problem completely. Similarly, manned aircraft experience accidents that result in tragedy. Airspace command and control can make pilotless aircraft in congested airspace seem less unpredictable. Unmanned rotary-wing aircraft require significantly less airspace to train and operate in than unmanned fixed wing. Limiting unmanned rotary-wing aircraft to military operations areas is a reasonable solution. In combat zones, it is possible to establish temporary flight corridors for unmanned rotary-wing operations for tactical resupply. Flight traffic in combat environments is usually not as busy as in national airspace. Many of the challenges facing unmanned fixed-wing aircraft are not applicable to unmanned rotary-wing aircraft. The Army can train, operate, and maintain aircraft with relatively little risk to human life or infrastructure if they operate in designated areas. In turn, training in small military operations areas in the United States will not limit the capabilities of an unmanned rotary-wing aircraft in the same way it will limit an unmanned fixed-wing aircraft.

Autonomy can be a force multiplier in manned and unmanned aircraft if the operators learn to test and trust their systems. In both manned and unmanned systems

autonomy reduces pilot workload and heightens situational awareness. In unmanned aircraft, autonomy represents the aircraft's ability to recover and land itself in conditions not conducive to humans—if the operator trusts the autonomous system.

Summary

The analysis provided in this chapter highlighted several issues remaining unanswered in the realm of unmanned aircraft. Mainly, the Department of the Army does not accept two of the three most important criteria. The first and last criteria, operations in degraded visual conditions and autonomy, are the least accepted based on the lack of trust in fully autonomous technology and newly experimental stages of unmanned rotary-wing aircraft in cargo and resupply roles. The second criterion, low maintenance cost, is a major benefit to the concept of unmanned aircraft in general. However, until technology is proven reliable and trusted to complete missions consistently, the Army will never experience the full benefits of these criteria. This analysis has determined that the 11 criteria thoroughly describe unmanned capabilities in support of tactical resupply missions. Further evaluation and research may develop concrete solutions to operating in degraded visual environments and fully autonomous operations.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This thesis examined the costs and benefits of employing rotary-wing unmanned aircraft in tactical resupply missions to support joint operations. Chapter 4 presented the analysis based on a comparison of manned and unmanned rotary-wing platforms against 11 evaluation criteria. This chapter presents the conclusions for each of the secondary research questions that help to answer the primary research question of this study: Should the Department of the Army develop and integrate rotary-wing, unmanned aircraft to support joint logistic missions? Finally, this chapter recommends actions that the U.S. Army may take and areas that require further study to more effectively and more efficiently conduct tactical resupply missions using unmanned rotary-wing aircraft.

Secondary Research Questions

SRQ 1: What can an unmanned rotary-wing aircraft provide to tactical logistic missions that a manned helicopter cannot?

The comparison of manned and unmanned rotary-wing aircraft relates directly to the primary research question. The results of this comparison provided evidence regarding whether the current Department of the Army reliance on manned rotary-wing air resupply is superior to unmanned rotary-wing resupply. To justify any changes to the current organization or policies, evidence must show that the current rotary-wing resupply method is less effective than unmanned rotary-wing resupply. The following evidence supports the adoption of an unmanned rotary-wing method for tactical resupply missions.

Unmanned rotary-wing aircraft remove the risk of dead, injured, or isolated pilots. Research has shown that the K-MAX has been successful in resupply missions in Afghanistan, suffering only minor accidents and limited damage costs. Another detailed benefit is the reduced cost to maintain unmanned rotary-wing aircraft. Several studies demonstrate that rotary-wing unmanned aircraft are less expensive to operate and maintain. With regard to the remaining criteria, this study shows that manned and unmanned rotary-wing aircraft are comparable. Where unmanned rotary-wing aircraft excel are in such categories as degraded visual environment, mission endurance, maintenance cost, and noise signature. Areas in which their capabilities do not measure up to those of manned aircraft include payload capacity, ability to carry the wounded, speed of delivery, and confined area landings. Eventually, unmanned aircraft may match or outperform manned aircraft in all categories except autonomy because this remains debatable. Autonomous technology for both aircraft systems is still unproven and requires further experimentation. Civilian and military pilots continue to closely monitor autonomous flight systems and are uncomfortable with unsupervised aircraft operations. Furthermore, the manpower requirements to operate manned and unmanned rotary-wing systems are comparable because the Army has not embraced autonomous technology. As long as the uncertainty and skepticism of autonomous technology remains, the Army will not experience the full benefits of unmanned rotary-wing systems.

SRQ 2: Why has the U.S. Army not researched, developed, and utilized cargo rotary-wing unmanned aircraft to the extent that the U.S. Navy and Marine Corps have?

This secondary research question corresponds to the primary research question by spotlighting the current mindset within the Department of the Army avoid or reject

unmanned rotary-wing program development. Understanding the reasoning behind this dominant and unique Army perspective provides insight into whether such a program could or should be aggressively pursued in the future.

This research shows that the Army did not pursue unmanned cargo rotary-wing aircraft because it had spent significant funds to modernize the current cargo and utility fleet and was satisfied with the modernized fleet's performance in combat operations and against competing fleets. Also, recently, defense budget cuts have paused new technology programs unproven in field-testing including some that could further develop unmanned aircraft technologies. Yet none of these reasons directly counter the potential benefits of unmanned rotary-wing aircraft. In fact, the U.S. Army had planned and budgeted an unmanned rotary-wing program but recently cancelled the funding. Realistically, the state of the U.S. economy and life span of the modernized cargo utility fleet will determine the timeline for further development of unmanned rotary-wing aircraft.

Although external factors, thus far, have prevented the Army from incorporating unmanned rotary-wing aircraft in its tactical resupply concept, the capabilities of unmanned rotary-wing aircraft are convincing enough to pursue a technology when the time is right.

SRQ 3: What is the potential organizational restructuring to the Department of the Army that would result when fielding cargo rotary-wing unmanned aircraft?

The answer to the third secondary research question explains the second and third order effects that could result from the implementation of an unmanned rotary-wing concept. New technology always incurs changes in doctrine, organization, training, materiel, leadership, personnel, and facilities (DOTMLPF). The ripple effect of new

materiel introduced into a large organization such as the U.S. Army cannot be managed properly without subsequent changes in other DOTMLPF variables.

Arguably, the U.S. Army is pausing the unmanned rotary-wing aircraft program for tactical resupply missions to fully understand how they can be integrated into the existing organizational structure. Recent issues with integrating unmanned fixed-wing aircraft into national airspace for training may have caused them to rethink the unmanned rotary-wing program. Additionally, in the last few years, unmanned fixed-wing platforms have switched organizational structures several times. They started out in military intelligence organizations and are now the responsibility of the aviation brigades. Much of this change stemmed from deficiencies in crew training and proficiency when unmanned aircraft pilots were not held to the same standards as manned aircraft pilots.

This research supports joint manned and unmanned cargo rotary-wing organizations. Unmanned rotary-wing aircraft could be organized within the aviation brigade structure; however, the Army has not yet analyzed whether they operate best as a separate unit, in which units they would be most effective, or if they operate best in large or small numbers. The Army also has yet to determine what should be the source for the personnel that operate from the aircraft. Manned pilots could be reassigned as unmanned pilots, much like the U.S. Air Force did with their unmanned aircraft program; or an entirely new career field could be created. Either option takes time and money to implement. Simply associating unmanned pilots with the aviation community does not solve the issue of manning, funding, training, equipping, and operating. This process involves many major components of the Department of the Army staff to ensure its success.

Certainly, the Army would prefer to avoid unnecessary organizational changes because of costly personnel and asset movements around the country. The fiscal situation will undoubtedly cause a pause in innovation. Programs that can analyze the effects across the DOTMLPF will be better off and likely receive remaining Army funds. As of now, the unmanned rotary-wing aircraft concept in the Army has not been experimented and tested with fidelity to continue implementation.

SRQ 4: What are the potential tactical changes the Department of the Army would have to implement to properly utilize cargo rotary-wing unmanned aircraft?

The answer to this secondary research question derives from the advantages and disadvantages of unmanned rotary-wing aircraft in tactical resupply missions, as described in chapter 4. Further analysis of the unmanned rotary-wing advantages with respect to tactics also supports the primary research question.

This research provides evidence that unmanned rotary-wing aircraft can be incorporated to increase tactical flexibility and success. Unmanned rotary-wing aircraft enhance the ground force in all tactical variables such as mission, enemy, troops, terrain, and time. When only manned resupply assets are available, to support most missions, the ground force commander must posture these assets around the illumination cycle or weather patterns. In contrast, the unmanned K-MAX is reliable in degraded visual conditions and can provide nearly 6,000 pounds of cargo. This capability can resupply at least a company of light infantry in one move. Tactically, a ground force of this size does not have to worry about outrunning their supply lines during low illumination or poor weather operations. The negative aspect of this technology is its inability to resupply heavy armored forces with petroleum products. At best, it can resupply heavy forces with

food, water, and small parts. Unmanned rotary-wing aircraft will not largely enhance major combat operations in heavy armored operations.

Against the enemy, the unmanned aircraft is most advantageous because no humans are at risk. Because it can operate in conditions that man cannot, low illumination and poor weather, it can survive in enemy contested environments. On the other hand, once identified by a reputable air defense system, the unmanned rotary-wing aircraft is, at most, as effective as manned rotary-wing platforms. Therefore, manned and unmanned aircraft will likely sustain similar losses in combat operations.

Unmanned technology can resupply in the same terrain as manned rotary-wing aircraft, and in similar or worse conditions. In most areas, with unmanned rotary-wing aircraft, ground forces can plan to maneuver without fear of losing resupply access. Continuous resupply allows the ground force to maintain a tempo conducive to effectively maneuver on the enemy objective.

Compared to manned aircraft, unmanned rotary-wing aircraft are less reliant on troops and manpower. Fewer troops are required to maintain and operate unmanned rotary-wing aircraft than for units operating manned aircraft. Although manned and unmanned aircraft require a comparable number of troops on the ground to recover cargo, using unmanned rotary-wing aircraft can reduce time restrictions or limitations for the ground force by enabling flexibility into the ground tactical plan. In addition to the atmospheric aspects, the ground force can operate an unmanned aircraft nearly continuously whereas they cannot with a manned aircraft. Manned aircrews have to switch out, which leaves gaps in coverage. Continuous coverage maximizes the ground force commander's time with respect to resupply operations.

Tactically, the unmanned rotary-wing aircraft is a sound concept for resupply operations. It covers gaps in coverage, takes pilots out of harm's way, and delivers in harsh conditions. The tactical changes the Army makes to integrate unmanned rotary-wing aircraft will be minimal because, in most respects, they mirror manned operations. The Army understands the tactical advantages, but will continue to research all aspects that may impact the organization before utilizing unmanned rotary-wing aircraft.

Primary Research Question

Should the Department of the Army develop and integrate rotary-wing, unmanned aircraft to support joint logistic missions?

The results of this thesis shows that the Department of Army should continue to develop and integrate unmanned rotary-wing aircraft for tactical resupply missions in joint operations. The current capability shown in the U.S. Marine Corps K-MAX and the potential for the A-160 provides strong evidence that these aircraft systems will provide value to the tactical resupply mission. Undeniably, unmanned rotary-wing aircraft can, on a limited basis and cost effectively, fill tactical resupply mission gaps. Less clear are questions regarding future advances in autonomous technology, shifting from wide area security operations to major combat operations, and changes across the DOTMLPF process. Currently, the Army seems hesitant to experiment with new concepts, content with an adequate existing modernized cargo helicopter fleet and facing a defense budget forecasted to continue to shrink over the next several years. Notwithstanding these considerations, until the Army fully experiments with the unmanned rotary-wing concept for resupply operations, it will not realize all of the potential benefits ahead.

Recommendations

The U.S. Army can implement unmanned rotary-wing aircraft by setting realistic expectations and goals for their future use. This study determined that unmanned rotary-wing aircraft do not have the payload capabilities to compete with manned aircraft. Therefore, the U.S. Army should not look to unmanned rotary-wing aircraft as a complete replacement for manned helicopters, but as an additional asset to fill gaps in manned aircraft coverage. Based upon this research, the U.S. Army should develop and employ a small team of unmanned rotary-wing aircraft for special resupply missions such as adverse weather, low illumination, or high threat areas. Utilizing these systems in this role will not only fill a capability gap, but will also allow time for experimentation and development at a reasonable pace.

Critical to the integration of unmanned rotary-wing aircraft is the rigorous experimentation of not only material aspects like autonomous technology, but throughout the DOTMLPF process. Because autonomous technology is relatively inexpensive compared to manned systems, testing small teams within the organization would be cost effective in the long run. Rigorous testing also solidifies confidence and trust in the emerging technology, training programs, and developing doctrine.

The unmanned rotary-wing program has the benefit of hindsight. To be successful, this program must capitalize on lessons learned from earlier unmanned aircraft programs, learning from the DOTMLPF successes and failures of the unmanned fixed-wing program in the U.S. Army and Air Force over the past 10 years.

Lastly, the U.S. Army should remain open to innovation during fiscal cuts to avoid being unprepared for the next conflict. Relying solely on existing technology while

new concepts sit idle, sets precedence for stagnation. The defense budgets may not improve until the American people deem there is a realistic threat approaching, but that may be too late. Incremental development and testing of this concept will ensure the Army is ready when it is time to mass-produce and operate unmanned rotary-wing aircraft for resupply.

Recommendations for Further Research

One area of this study that requires additional research is the integration of manned and unmanned rotary-wing aircraft into the U.S. Army organization to include airspace integration and deconfliction. Understanding how unmanned and manned rotary-wing aircraft function and operate together will ease the transition into Army aviation units. Another area lacking research is the role of unmanned rotary-wing aircraft in homeland defense, humanitarian assistance, and disaster relief missions. This study only analyzed impacts of unmanned rotary-wing aviation on military combat operations. Another area for additional research is beyond line-of-sight communications other than satellite communications. A major part of unmanned technology is the satellite communications providing GPS navigation. Satellite technology is vulnerable to jamming and only line-of-sight communications can navigate unmanned aircraft to safety. The last area for additional research is mission sets utilizing unmanned rotary-wing aircraft such as medical evacuation and personnel recovery. Unmanned rotary-wing aircraft could possibly be the last effort to save an American soldier desperately awaiting help while the enemy overcomes manned assets.

BIBLIOGRAPHY

Books

Austin, Reg. *Unmanned Aircraft Systems: UAVS Design, Development, and Deployment*. West Sussex, UK: A. John Wiley and Sons, 2010.

Clausewitz, Carl von. *On War*. Michael Eliot Howard and Paret, Peter. Princeton: Princeton University Press, 2008.

Articles

Allen, Kevin M. "Army Air Crews." September 15, 2013. www.armyaircrews.com (accessed October 25, 2013).

"Army Shows interest in the KMAX." *Helicopter News*. January 17, 2012.

Betson, Captain Ben. "A Case Against an Unmanned Cargo Aerial System." *Army Sustainment* 44, no. 5 (September-October 2012): 28.

Braybook, R. "Practical Lessons...and Remedies." *Armada International* 33, no. 3 (June 2009): 1-40.

Braybook, Ray. "Three D Mission—Dull, Dirty and Dangerous." *Armada International* (January 2004).

Colucci, Frank. "Digging Out From Brown Out." *Vertiflite* 53, no. 1 (Spring 2007): 50-55.

Dillow, Clay. "Army's Smart 'Sense and Avoid' System Key to Letting Drones Cruise Domestic Skies." *Popular Science*. July 9, 2012. <http://www.popsci.com/technology/article/2012-07/armys-new-sense-and-avoid-system-paves-way-drones-domestic-skies> (accessed October 21, 2013).

Edwards, Bryan, and Charles Fox. *Revolutionary Concepts of Helicopter Noise Reduction-S.I.L.E.N.T Program*. Edited by Langley Research Center. Hampton, VA: National Aeronautics and Space Administrations, May 2009.

Fulghum, David. "Precision Kills." *Aviation Week & Space Technology* 174, no. 7 (February 2012): 50. <http://connection.ebscohost.com/c/articles/73956245/precision-kills> (accessed March 31, 2013).

General Dynamics. *Future Modular Force Resupply Mission for Unmanned Aircraft Systems (UAS)*. Fairfax, VA: General Dynamics. 2010.

- Gormley, Dennis M. "Addressing the Spread of Cruise Missiles and Unmanned Aerial Vehicles (UAVs)." Center for Nonproliferation Studies (CNS), Washington, DC, March 2004. <http://www.nti.org/analysis/articles/addressing-spread-cruise-missiles> (accessed April 2, 2010).
- Hirschberg, Mike. "DARPA's Legacy Takes Flight: Contribution to Aeronautics." http://websearch.darpa.mil/search?q=takes%20flight&btnG=Search&entqr=0&ud=1&sort=date:D:L:d1&output=xml_no_dtd&oe=UTF-8&ie=UTF-8&client=default_frontend&proxystylesheet=default_frontend&site=default_collection (accessed July 14, 2013).
- Kramer, Melody. "Q&A With a Pilot: Just How Does Autopilot Work?" *National Geographic Daily News*. July 9, 2013. <http://news.nationalgeographic.com/news/2013/07/130709-planes-autopilot-ask-a-pilot-patrick-smith-flying-asiana/> (accessed October 7, 2013).
- Langston, Lee S., and George Opdyke Jr. "Introduction to Gas Turbines for Non-Engineers." *Global Gas Turbine News* 37, no. 2 (1997): 9.
- Matthews, William. "Unmanned K-MAX Delivers: USMC Considers 'Synchropter' for Cargo Drops in Hostile Terrain." *Defense News*. February 22, 2010. <http://www.defensenews.com/print/article/20100222/DEFBEAT01/2220311/Unmanned-K-MAX-Delivers> (accessed September 10, 2013).
- McCarthy, Mike. "Unmanned Cargo Helicopter shows Sustainability in Test." *Defense Daily*. September 6, 2011. <http://search.proquest.com/docview/899263700?accountid=28992> (accessed April 3, 2013).
- McCoy, John V. "Unmanned Aerial Logistics Vehicle—A Concept Worth Pursuing." *Army Logistician* (March-April 2004). http://www.findarticles.com/cf_dls/m0PAI/2_36/114487531/p1/article.jhtml?term= (accessed 5 April 2004).
- McHale, John. "Sensitive and Tireless, High Endurance UAVs Sense What Humans Cannot." *Military and Aerospace Electronics*. April 2007. <http://www.militaryaerospace.com/articles/print/volume-18/issue-4/features/special-report/sensitive-and-tireless-high-endurance-uavs-sense-what-men-cannot.html> (accessed July 12, 2013).
- McLeary, Paul. "US Army Takes it Slow on Cargo UAV Program." *Defense News*. April 6, 2012. <http://www.defensenews.com/article/20120406/DEFREG02/304060003/U-S-Army-Takes-Slow-Cargo-UAV-Program> (accessed July 12, 2013).
- Munoz, Carlos. "The Army Wants a Man in the Loop." *Breaking Defense*. August 16, 2011. <http://breakingdefense.com/2011/08/army-wants-man-in-the-loop-on-armed-uas-ops/> (accessed October 20, 2013).

- Osborn, Kris. "Army to deploy vertical take-off UAS." SP's MAI, December 22, 2011. General OneFile Web. <http://www.army.mil/article/71269/> (accessed April 1, 2013).
- Parsons, Dan. "Worldwide, Drones Are In High Demand." *National Defense*. May 2013. <http://www.nationaldefensemagazine.org/archive/2013/May/Pages/Worldwide,DronesAreinHighDemand.aspx> (accessed September 30, 2013).
- Robinson, Brian. "FCS Cancellation Confirmed, Army Modernization Changes Course: Several Smaller Programs to take the place of Future Combat Systems." *FCW: The Business of Federal Technology*. June 24, 2009. <http://fcw.com/articles/2009/06/24/army-future-after-fcs.aspx> (accessed August 2, 2013).
- Sanborn, James K. "Beacon Improves UAV's Cargo-Delivery Accuracy." *Marine Corps Times*, July 8, 2012. <http://www.marinecorpstimes.com/article/20120708/NEWS/207080314/Beacon-improves-UAV-s-cargo-delivery-accuracy> (accessed October 1, 2013).
- Staff Writers. "DARPA Developing Next Generation of Vertical Flight Technology." *Space Daily*. February 26, 2013. http://www.spacemart.com/reports/DARPA_Experimental_Aircraft_Program_to_Develop_the_Next_Generation_of_Vertical_Flight_999.html (accessed April 1, 2013).
- Staff, Defense Industry Daily. "Unmanned Hellos: The USMC's Unmanned Cargo Helicopters." *Defense Industry Daily*. March 27, 2013. <http://www.defenseindustrydaily.com/USMC-Looks-for-an-Unmanned-Cargo-Helicopter-06672/> (accessed October 1, 2013).
- Trimble, Stephen. "US Army Launches Hunt for Autonomous Cargo Aircraft." *Flight International*. January 24, 2012. <http://www.docstoc.com/docs/160108328/Flight-International-2012-01-24> (accessed April 1, 2013).
- Valavanis, Kimon P. ed. *Advances in Unmanned Aerial Vehicles: State of the Art and the Road to Autonomy*. The Netherlands: Springer, 2007.
- "VTOL UAS: Vertical Take-off and Landing Unmanned Aerial System." Advertisement Brochure. Swiss UAV, 2011.
- Warwick, Graham. "Sky Patrol." *Aviation Week & Space Technology* 174, no. 32 (September 3, 2012): 55. Military & Government Collection, EBSCOhost (accessed March 31, 2013).
- Withington, Thomas. "Synthetic View of Drones." *Armada International* (June 2008): 40.

Research Projects

Peterson, Capt. Troy M., USMC, and LT. Jason R. Staley, USN. "Case Analysis of Cargo Unmanned Aircraft System (UAS) Capability in Support of Forward Deployed Logistics in Operation Enduring Freedom (OEF)." Acquisition Research Sponsored Report, Naval Postgraduate School, Monterey, CA, October 2011.

Wegner, Major Robert Glenn. "A Pilotless Army in the Megalopolis." Monograph, School of Advanced Military Studies, Fort Leavenworth, KS, 2004.

Williams, Major Jason T., USAF. "Tactical Unmanned Airlift: A Business Case Study." Graduate Research Project, Air Force Institute of Technology, Wright-Patterson AFB, OH, 2010.

Government Documents

Chairman of the Joint Chiefs of Staff. Joint Publications 3-52, *Joint Airspace Control*. Washington, DC: Government Printing Office, May 2010.

———. Joint Publication (JP) 4-0, *Joint Logistics*. Washington, DC: Government Printing Office, July 2008.

Department of Defense. *Annual Aviation Inventory and Funding Plan Fiscal Years (FY) 2014-2043*. Washington, DC: Government Printing Office, May 2013.

———. *Operation and Maintenance Overview Fiscal Year 2014 Budget Estimates*. Washington, DC: Government Printing Office, April 2013.

Development, Concepts and Doctrine Centre. Joint Doctrine Note (JDN) 2/11, *The UK Approach to Unmanned Aircraft Systems*. Shrivenham, UK: United Kingdom Ministry of Defence, March 2011.

Gaydos, Steven J., M. J. Harrigan, and Alastair J. R. Bushby. *Ten Years of Spatial Disorientation in U.S. Army Rotary-Wing Operations*. Reprint. Fort Rucker, AL: Department of the Army, U.S. Army Aeromedical Research Laboratory, October 2012.

Naval Resource Advisory Committee. *Report on Engine Noise Reduction*. April 2009. http://www.nrac.navy.mil/docs/2009_FINAL_Jet_Noise_Report_4-26-09.pdf (accessed September 2, 2013).

United States Air Force. *Air Force Unmanned Aerial System (UAS) Flight Plan 2009-2047*. Washinton, DC: United States Air Force Deputy Chief of Staff, Intelligence, Surveillance, and Reconasaince, July 23, 2009.

United States Army Aviation Center of Excellence. *US Army Unmanned Aircraft Systems Roadmap 2010-2035*. Fort Rucker, AL: United States Army, 2010.

United States Army. Army Regulation (AR)70-75, *Survivability of Army Personnel and Material*. Washington, DC: Government Printing Office, May 2005.

———. *Commander's Aircrew Training Program*. Washington, DC: Government Printing Office, 2007.

———. Field Manual (FM) 3-04.113, *Cargo and Utility Helicopter Operations*. Washington, DC: Government Printing Office, December 2007.

———. Field Manual (FM) 3-04.203, *Fundamentals of Flight*. Washington, DC: Government Printing Office, May 2007.

———. Field Manual (FM) 4-0, *Sustainment*. Washington, DC: Government Printing Office, April 2009.

———. Field Manual (FM) 4-02.02, *Medical Evacuation*. Washington, DC: Government Printing Office, May 2007.

———. Training Circular 3-04.93, *Aeromedical Training for Flight Personnel*. Washington, DC: Government Printing Office, August 2009.

United States Congress. House. Committee on Armed Services. Subcommette on Air and Land Forces, *Hearing on National Defense Authorization Act for Fiscal Year 2008 and Oversight of Previously Authorized Programs Before the Committee on Armed Services, House of Representatives, One Hundred Tenth Congress, First Session: Air and Land Forces Subcommittee Hearing on Budget Request on Unmanned Aerial Vehicles (UAV) and Intelligence, Surveillance, and Reconnaissance (ISR) Capabilities*. Washington, DC: Government Printing Office, April 2007.

United States Department of Transportation, Federal Aviation Administration. *Instrument Procedures Handbook*. Vols. FAA-H-8261-1a. Washington, DC: Government Printing Office, 2007.

United States Marine Corps Center for Lessons Learned. *Air Operations in Support of Logistics*. Quantico, VA: Government Printing Office, 2013.